CUTLER-HAMMER

AIL TYPE 70

Instruction Handbook for .....

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RASP

AIL TYPE 70
HOT-COLD BODY
STANDARD NOISE GENERATOR
PART NUMBER 07004

LAB-39

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CUTLER-HAMMER

AIRBORNE INSTRUMENTS LABORATORY
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AIL DIVISION

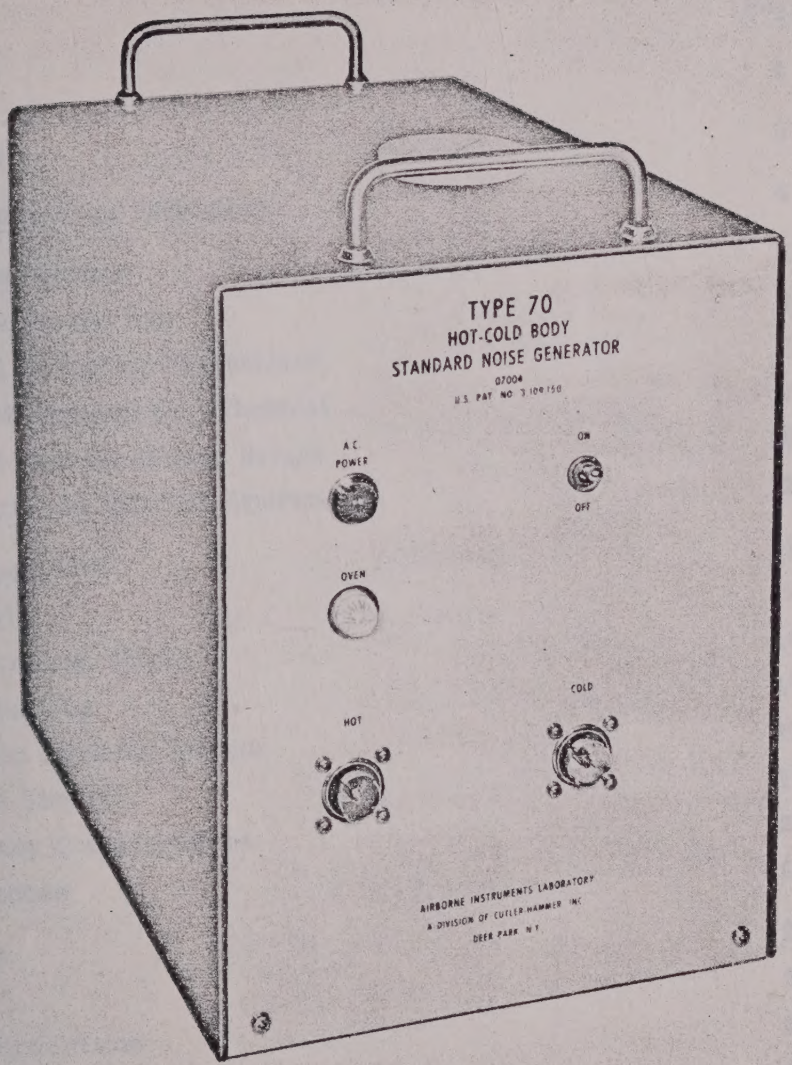

FIGURE 1. HOT-COLD BODY STANDARD NOISE GENERATOR

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I. INTRODUCTION

The AIL Type 70 Hot-Cold Body Standard Noise Generator (Part No. 07004) is used to accurately measure the noise characteristics of low-noise equipment over the frequency range of 0 to 6 Gc. It is particularly well suited for precise noise figure measurements of equipment such as parametric amplifiers and for the calibration of other less accurate noise generators by comparative noise figure measurements.

The noise generator uses two resistive elements, one immersed in liquid nitrogen (77.3°K) and the other mounted in a temperature-controlled oven (373.2°K). Each termination has a resistance of 50 ohms at its operating temperature. Two quick disconnect receptacles on the front panel permit connecting the unit under test to either the 77.3°K load or the 373.2°K load.

VI. MAINTENANCE

Maintenance of the noise generator will consist of replacement of defective parts after the following checks have isolated the part or parts.

A. OVEN

The oven is designed to heat the hot termination to 373.2°K (212°F) and will cycle on and off as indicated by the OVEN light on the front panel. Cycling of this light indicates that the oven is operating properly. To externally monitor the temperature of the HOT termination, a temperature indicating instrument may be connected to the internal thermocouple by means of the mating plug supplied with the noise generator. Several precautions should be observed when using this feature:

1. The internal thermocouple and mating connectors are a copper-constantan combination. The leads connecting the mating plug to the indicator should be the same.
2. Polarity of the connecting leads should be observed. At the temperature of interest the copper wire will be positive, the constantan negative.
3. If a direct reading temperature indicator is used, it must have a scale that follows the copper-constantan temperature-millivolt curve.
4. Because of the mechanical construction of the oven and HOT termination assembly, it is physically impossible to attach the thermocouple to the active portion of the terminating resistor without seriously degrading its critical RF characteristics. As a consequence, the temperature indication will always be about 1°C below the actual operating temperature. The primary purpose of the thermocouple is to indicate a serious error in oven setting and excessive temperature excursions during the oven cycle.

B. HOT TERMINATION

The measurement of SWR with AC power applied to the unit will determine if the termination has been damaged. If the SWR exceeds 1.15, return the unit to the factory for repair.

C. COLD TERMINATION

The same check for SWR described for the hot termination applies to the cold termination. However, water condensation, or the formation of liquid oxygen can cause a high SWR (see Section V-D). If the COLD termination exhibits an SWR greater than 1.15, gently tilt the unit from the normal bench position, first forward, then backward. Repeat a number of times. Tilting causes the liquid oxygen to flow away from the termination to a region of higher temperature where it will boil off.

If the unit still fails to operate properly, it should be returned to the factory for repair.

D. FLASK

The flask should give trouble-free service for many years. However, leakage may occur in the vacuum seal which will decrease the life of a charge of liquid nitrogen. If this occurs, the unit should be returned to the factory for repair.

E. TROUBLESHOOTING

A schematic diagram (Figure 9) and a replaceable parts list (Section VII) are included to assist with routine troubleshooting and repair of the noise generator.

F. RETURN OF EQUIPMENT TO FACTORY FOR REPAIRS

If it is necessary to return the equipment to the manufacturer for repair, please write first to the AIL Sales Department, giving the type and serial number of the unit, complete information concerning the nature of the failure, and the manner in which the equipment was used when failure occurred. Special instructions will then be supplied to the customer for shipping the unit back for repairs. All equipment should be packed and shipped in accordance with these instructions, with transportation charges prepaid. A failure report should accompany the unit.

2. SWR DIFFERENTIAL

The difference in SWR between the HOT and COLD terminations of the noise generator is held to a very close tolerance by matching the SWR's of the two terminations, in both magnitude and phase, over the operating frequency range of the instrument. However, even this small change in source impedance may have a significant effect on the gain of some high-gain, negative-input resistance devices (parametric amplifiers, masers, etc.). The change in gain due to source impedance variations for high-gain amplifiers (greater than 15 db) can be closely approximated by equation 5-21.

$$\frac{\Delta G}{G} \approx \frac{\Delta |Z_o|}{|Z_o|} G \qquad (5\text{-}21)$$

where

G = amplifier power gain

Z_o = source impedance

The change in amplifier gain will cause an error in the measured value of the Y-factor. The true Y-factor can be obtained from equation 5-22.

$$Y = Y \text{ measured (db)} - \Delta G(\text{db}) \qquad (5\text{-}22)$$

ΔG can be measured by coupling a test signal into the amplifier input through a 20- or 30-db directional coupler and observing the output as the input is moved from the COLD to the HOT termination. The test signal power should be at least 15 to 20 db greater than the noise power at the amplifier input, but not large enough to cause limiting in the system. A second solution would be to provide isolation, by means of a ferrite device, between the amplifier input and the noise source. This would reduce the impedance variation seen by the amplifier. The insertion loss of the isolator would add directly (in db) to the overall system noise figure and must be accurately measured and subtracted from the measured value of noise figure.

3. SECOND-STAGE NOISE CONTRIBUTIONS

If the gain of the unit under test is sufficiently low, the noise generated by the amplifier that follows the unit under test will contribute significantly to the

measured value of noise figure. The extent of this second-stage noise contribution can be determined by measuring the gain of the unit under test and the noise figure of the following amplifier. Equation 5-23 can then be used to determine the true noise figure of the unit under test.

$$F_1 = F_{12} - \frac{F_2 - 1}{G_1} \qquad (5\text{-}23)$$

where

F_1 = noise figure of unit under test

F_2 = second-stage noise figure

F_{12} = overall measured noise figure (unit under test and second stage)

G_1 = power gain of unit under test

NOTE

These quantities are all expressed as power ratios, not in db.

4. IMAGE RESPONSE

The following applies only to conventional receiver applications in which the image channel is not normally used to convey information. Image response can be an important factor in the measurement of low-noise systems consisting of a wide-band preamplifier followed by a heterodyne receiver. If the preamplifier has nearly equal gain at both the image frequency and the signal frequency, its noise figure will be deteriorated by the amplification of input noise at the image frequency and a Y-factor measurement alone will not yield the true noise figure. Equation 5-24 shows the relation between true noise figure (F_T) and the noise figure computed from equation 4-1 (based on a Y-factor measurement).

$$F_T = \left(1 + \frac{G_{im}}{G_{sig}}\right) F_m \qquad (5\text{-}24)$$

where

F_T = true noise figure

F_m = noise figure computed from a Y-factor measurement

G_{im} = image channel gain

G_{sig} = signal channel gain

5. CABLE LOSSES

If a cable or other transmission circuit is used between the noise generator and the unit under test, any losses that are introduced will cause an error in the measured noise figure. The insertion loss of the transmission circuit will add directly (in db) to the overall system noise figure, and therefore, should be measured accurately and subtracted from the measured noise figure to obtain the true noise figure.

G. REFERENCES

1. "IRE Standards on Electron Tubes: Definition of Terms, 1962," (62 IRE 7.S2) Proceedings of the IEEE, Vol 51, No. 3, 1963, p 434-435, March 1963.
2. "Description of the Noise Performance of Amplifiers and Receiving Systems," IRE Subcommittee 7.9 on Noise. Proceedings of the IEEE, Vol 51, No. 3, p 436-442, March 1963.
3. R. L. Sleven, "Clarification of Subtle Noise Figure Measurement Problems," AIL Technical Memorandum No. 44.

F. ACCURACY CONSIDERATIONS

The following paragraphs point out some of the more common sources of error in noise measurements. Complete derivations are not provided; however, these can be obtained from the cited references.

1. TERMINATION TEMPERATURE

The effect of errors in the assumed values of termination temperatures are shown in Figure 10. This is a nomograph which can be used to determine the noise figure measurement error when the termination temperature errors are known. The effect of the HOT termination on this error will generally be small as long as its temperature remains within the rated limits. The COLD termination temperature can also deviate from the assumed value as a result of any or all of the following:

Purity of liquid nitrogen - this can seriously affect the boiling point temperature and, for maximum accuracy, should be checked with the supplier.

Contamination of liquid nitrogen - oxygen present in the air will condense at a temperature about $11^{\circ}C$ higher than that of boiling nitrogen; therefore, exposure of the nitrogen can result in a mixture of the two elements. This mixture will boil at a temperature higher than that of pure liquid nitrogen, causing an error in the COLD termination temperature. The flask in the Hot-Cold Body Standard Noise Generator is designed to minimize the exposure of liquid nitrogen and reduce the probability of such contamination.

Atmospheric pressure - pure liquid nitrogen boils at $77.3^{\circ}K$ at sea level (760 mm Hg). A decrease in atmospheric pressure (such as encountered at high altitudes) will reduce the boiling point about $0.3^{\circ}K$ per thousand feet above sea level. At 5000 feet altitude, this would introduce an error of less than -0.03 db in the measured value of noise figure. For maximum accuracy, the liquid nitrogen temperature can be determined from equation 5-20.

$$\Delta T = 19 \log_{10} \frac{P}{760} \qquad (5\text{-}20)$$

where

ΔT = change in the boiling point of liquid nitrogen,

P = local atmospheric pressure in millimeters of mercury.

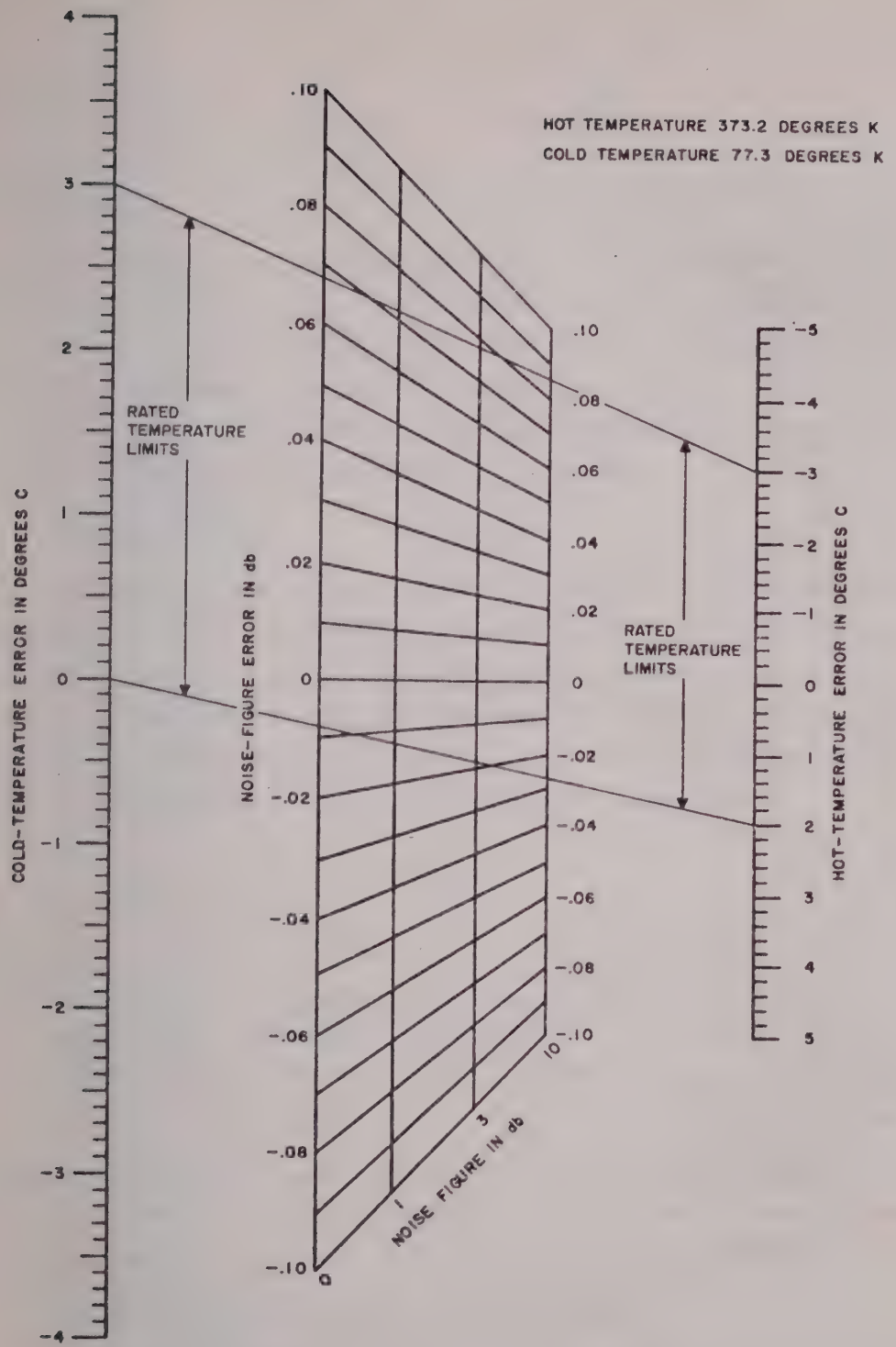

FIGURE 10. DETERMINING ERROR IN NOISE FIGURE AS FUNCTION OF ERROR IN HOT AND COLD TEMPERATURES

V. THEORY OF OPERATION

A. GENERAL

To discuss the operational theory basic to noise measurement made with the hot-cold noise generator, it is necessary to define the terms and quantities involved. This section is devoted to a brief development of the basic relations between noise power, effective input noise temperature, and noise figure. Further information and more detailed derivations can be obtained by consulting the references noted at the end of this section.

1. NOISE POWER

Throughout this section, reference is made to noise power originating from various sources. The definitions and measurements are in terms of the equivalent thermal noise power, that is, the noise generated as a result of the thermally-agitated random motion of electrons in a conductor. This is sometimes referred to as Johnson noise. Nyquist's theorem defines the relation between noise power and temperature. The result is given in equation 5-1.

$$N = KT \qquad (5\text{-}1)$$

where

N = noise power per unit bandwidth which would be delivered to a conjugately matched load,

K = Boltzmann's constant (1.38×10^{-23} joules/^{o}K),

T = temperature in degrees Kelvin.

Equation 5-1 states that the noise power per unit bandwidth available at the terminals of a resistor is directly proportional to the absolute temperature. Note that N is independent of the resistance value and the type of resistor.

2. EFFECTIVE INPUT NOISE TEMPERATURE

If all the noise generated within a network is referred to its input terminals, the noise power output of the network is:

$$N_o = N_{op} G \qquad (5\text{-}2)$$

where:

N_{op} = noise power available from all sources referred to the input terminals,

G = ratio of the signal power delivered to the load to the signal power available at the input terminals (transducer gain).

Using equation 5-1, a temperature can be assigned to N_{op} so that:

$$N_{op} = KT_{op} \tag{5-3}$$

T_{op} is the operating noise temperature of the network and is sometimes useful when describing the overall noise performance of a system under actual operating conditions. N_{op}, the equivalent input noise power, can be related to the sum of two distinct components as shown in equation 5-4.

$$N_{op} = N_i + N_e \tag{5-4}$$

where

N_i = noise power generated by the input termination,

N_e = effective input noise power contributed by the network only.

Again, using equation 5-1,

$$N_i = KT_i \tag{5-5}$$

and

$$N_e = KT_e \tag{5-6}$$

T_i is the temperature of the input termination. T_e is the effective input noise temperature and is generally used when describing the noise performance of low-noise devices such as masers and parametric amplifiers. By combining equations 5-2 through 5-6, T_e can be related to the operating noise temperature, T_{op}, by:

$$T_{op} = T_i + T_e \tag{5-7}$$

and to the network output noise power by:

$$N_o = K (T_i + T_e) G \tag{5-8}$$

3. NOISE FIGURE

Noise figure is probably the most commonly used measure of amplifier noise performance. It can be expressed as the ratio of the noise power output of a network to the noise power output of an ideal noiseless network of otherwise identical characteristics WHEN THE INPUT TERMINATION IS AT 290°K (as defined by the IRE Standards on Electron Tubes). This is expressed mathematically in equation 5-9.

$$F = \frac{N_o}{GN_i} \tag{5-9}$$

Noise figure is also sometimes defined as the ratio of the input signal-to-noise ratio to the output signal-to-noise ratio when the input termination is at 290°K. This is expressed in equation 5-10.

$$F = \frac{S_i/N_i}{S_o/N_o} \tag{5-10}$$

It can be seen that these two expressions are equivalent if it is noted that

$$\frac{S_i}{S_o} = \frac{1}{G} \tag{5-11}$$

Noise figure can be related to effective input noise temperature by combining equations 5-8, 5-9, and 5-10:

$$F = \frac{T_i + T_e}{T_i} \tag{5-12}$$

and, noting the restriction on T_i by the definition:

$$F = \frac{T_e}{290} + 1 \tag{5-13}$$

B. MEASUREMENT THEORY

Section IV describes some of the methods used to measure effective input noise temperature and noise figure using the Hot-Cold Body Standard Noise Generator. The input to the network under test is first terminated by the COLD termination at a temperature T_1. An output reference level indicative of the noise power out of the system (N_{o_1}) is then noted. Substituting the known value of T_1 for T_i in equation 5-8, the expression for N_{o_1} can be written:

$$N_{o_1} = K (T_1 + T_e) G \qquad (5\text{-}14)$$

The network input is then connected to the HOT termination at a temperature T_2. As noted, the output indication will increase. The noise output power under these conditions can be written:

$$N_{o_2} = K (T_2 + T_e) G \qquad (5\text{-}15)$$

An accurately known amount of attenuation is then inserted between the network output and the output level indicator. This attenuation is adjusted so that the output level is the same as when the network was terminated by the COLD termination. The required amount of attenuation is equal to the ratio of N_{o_2} to N_{o_1}; this ratio is called the Y-factor and can be expressed as:

$$Y = \frac{N_{o_2}}{N_{o_1}} \qquad (5\text{-}16)$$

1. EFFECTIVE INPUT NOISE TEMPERATURE

Once the Y-factor has been measured, T_e can be computed by substituting equations 5-14 and 5-15 into 5-16:

$$Y = \frac{T_e + T_e}{T_i + T_e} \qquad (5\text{-}17)$$

Solving equation 5-17 for T_e:

$$T_e = \frac{T_2 - YT_1}{Y - 1} \qquad (5\text{-}18)$$

If T_2 and T_1 are accurately known, and Y is measured, equation 5-18 can be used to calculate the effective input noise temperature, T_e. In the Hot-Cold Body Standard Noise Generator, T_2 is set to 373.2°K by an accurate, highly stable, thermostatically-controlled oven; T_1 is fixed at 77.3°K by immersion of the termination in a container of liquid nitrogen.

2. NOISE FIGURE

The noise figure of the unit under test can be determined by substituting equation 5-18 into equation 5-13. The result is given in equation 5-19:

$$F = \frac{\frac{T_2}{290} - Y\frac{T_1}{290}}{Y - 1} + 1 \qquad (5\text{-}19)$$

Equations 5-18 and 5-19 were given earlier as equations 4-2 and 4-1, respectively, and are plotted in Figure 4.

C. TERMINATIONS

The two connectors on the Hot-Cold Body Standard Noise Generator are connected to short rigid lengths of 50-ohm coaxial transmission line that are terminated by film resistors. At the operating temperatures, the voltage reflections are extremely small. Each assembly is located in a carefully controlled environment; the HOT termination is an accurate, stable oven; the COLD termination in a flask filled with liquid nitrogen.

1. HOT TERMINATION

The HOT termination is located within an oven that keeps the temperature of the terminating resistor at 373.2°K (100°C). The heater, sensing element, and control circuits are completely contained within the oven enclosure. A thermocouple junction (copper-constantan) is attached to a probe near the terminating resistor. The thermocouple leads are brought out to a connector at the rear of the unit. A mating plug for this connector is supplied with the unit.

2. COLD TERMINATION

The temperature of the cold termination is maintained at 77.3°K, the temperature of the boiling liquid nitrogen. The termination is inserted into the

nitrogen through a hole in the side wall of the Dewar flask, about two-thirds of the way down from the top of the flask.

D. NITROGEN FLUSHING SYSTEM*

The interior surfaces of the cold termination are at a temperature (77.3°K) that is lower than the freezing point of water vapor (0°C) and lower than the condensation temperature of oxygen (88°K). The formation of ice and liquid oxygen, which normally occurs when air comes in contact with these cold surfaces, will become evident by a serious degradation of the SWR of the cold termination. In order to avoid these effects, a nitrogen flushing system is used in this equipment. The nitrogen vapor available in the top of the flask is used to maintain an atmosphere of dry nitrogen in the cold termination. When the flask is initially filled and the nylon stopper is secured in place, the boiling nitrogen builds up a pressure in the flask. This pressure forces nitrogen gas through a tube that connects the top of the flask to a pressure manifold near the cold termination assembly. A heater in the manifold raises the temperature of the gas to minimize the formation of frost in the system. The manifold regulates the flow of nitrogen gas through an aperture in the outer wall of the termination. A continuous flow of nitrogen gas into this area and out through the connector is maintained during operation, thereby purging the area of air and water vapor.

E. CIRCUIT THEORY

Figure 9, the schematic diagram, shows the simplicity of the electrical circuits within the Hot-Cold Body Standard Noise Generator. Isolation transformer T1 has a split primary, which allows converting the unit to 230-volt operation. Power for the oven and the manifold heater is obtained from the transformer secondary. The neon AC ON indicator light I1 is connected across the secondary and comes on to indicate that the unit is energized. The OVEN neon indicator light I2, operates in parallel with the oven heater and comes on to indicate oven heater cycling. The dropping resistors for these lamps are part of the lamp holder assembly.

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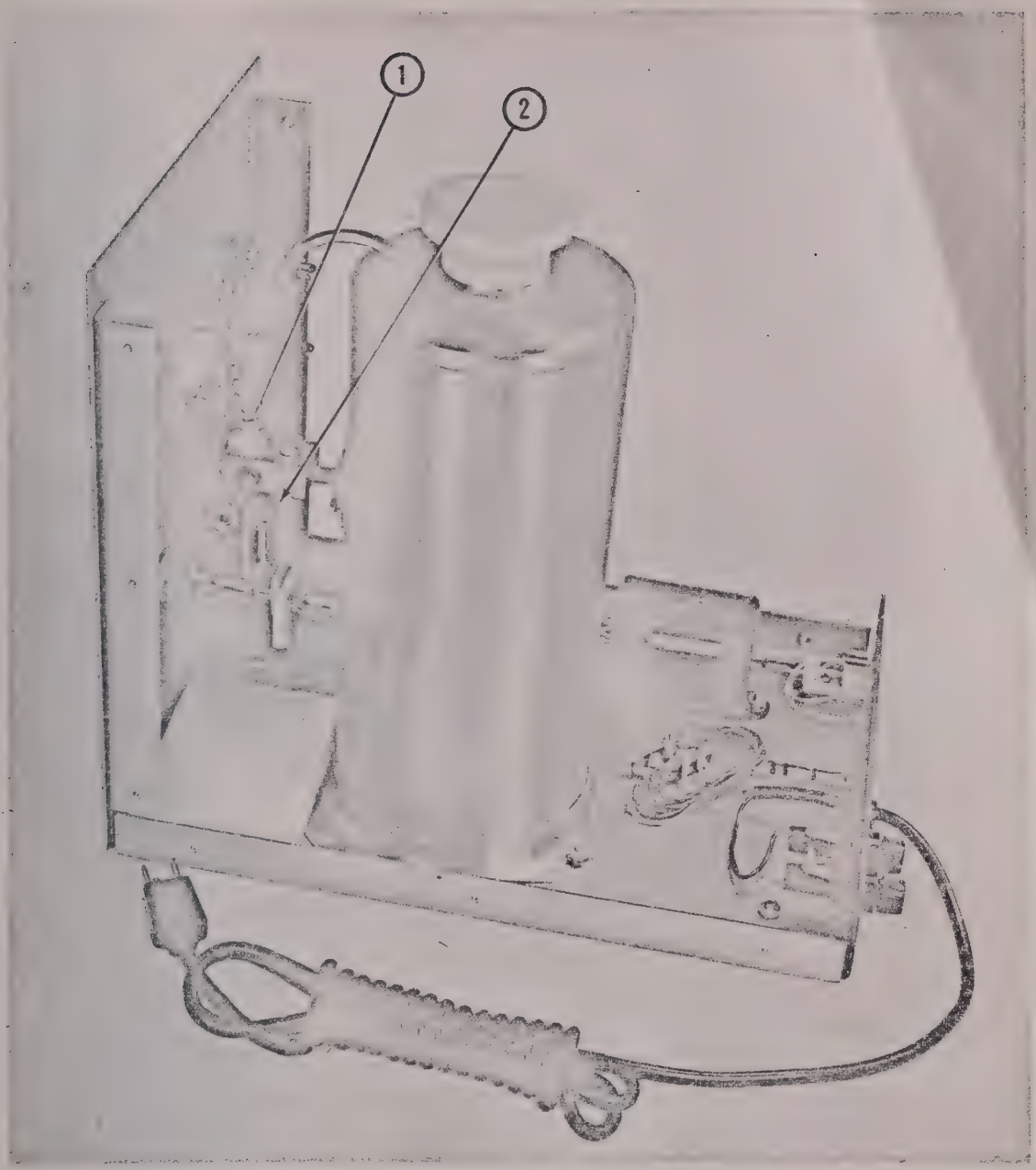
* NOTE: This system is protected by U. S. Patent No. 3,109,150, 29 October 1963.

VII. LIST OF REPLACEABLE PARTS

Reference Designation	Description	Part Number
F1, F2	Fuse	AGC ½
S1	Switch	C-H 8360K7
I1, I2	Lamp, neon	GE NE-51
T1	Transformer, isolation	Triad N-68X
	Thermocouple jack	Minneapolis-Honeywell 728096
	GR/N adapter	G-R 874 QNJA
	Dewar flask	AIL Dwg 118062
	Nylon cap, flask	AIL Dwg 205842
	Manifold assembly (see Figure 11)	AIL Dwg 205841
	Heater cartridge (see Figure 11)	AIL Dwg 205857



1. Heater cartridge
2. Manifold assembly

FIGURE 11. LOCATION OF COMPONENTS OF HOT-COLD BODY STANDARD NOISE GENERATOR

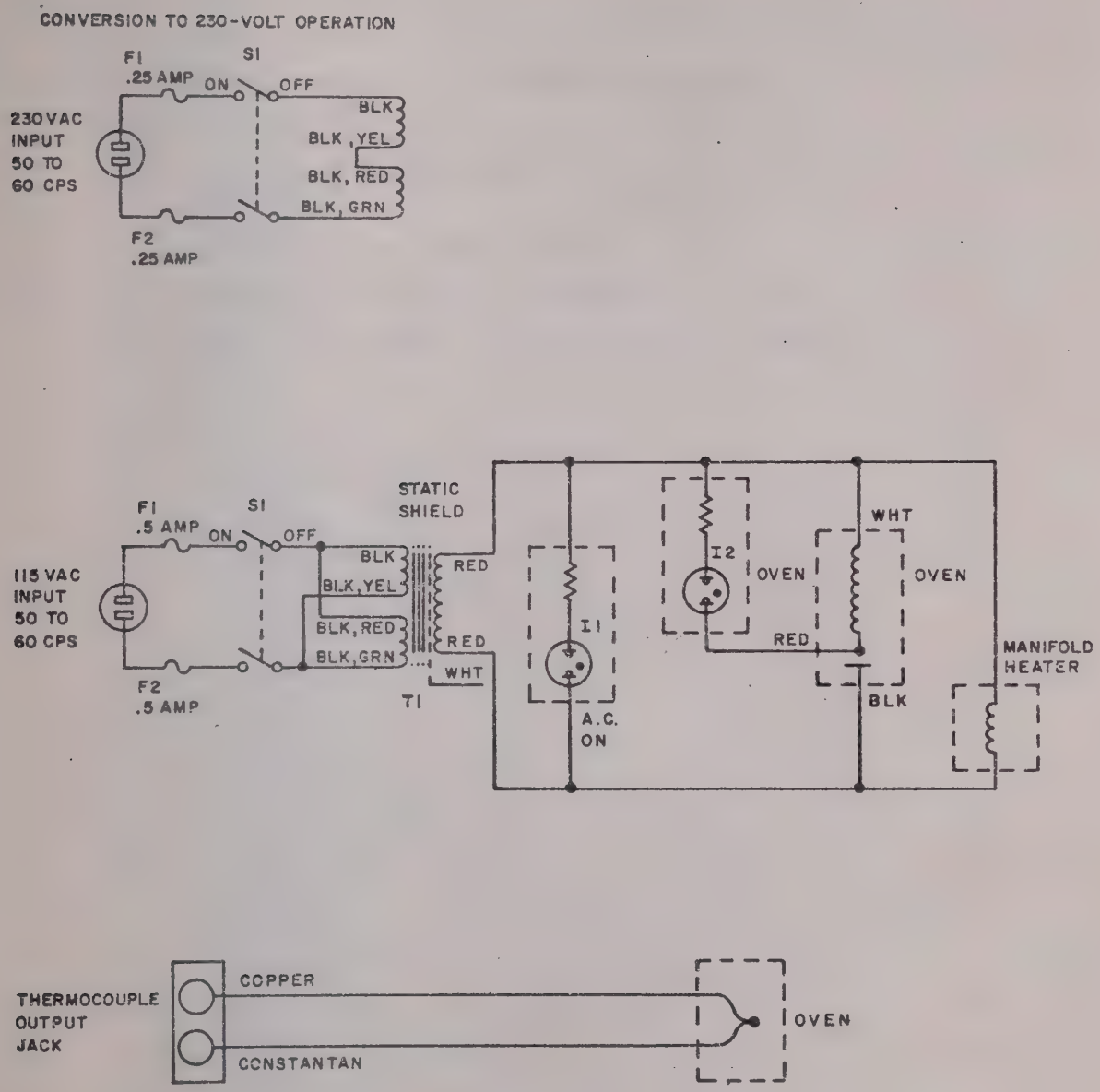


FIGURE 9. SCHEMATIC DIAGRAM, HOT-COLD BODY STANDARD NOISE GENERATOR, TYPE 70, PART NO. 07004

E. CONVERTING TO 230-VOLT OPERATION

When delivered, the noise generator is wired for 115-volt input operation. To convert the unit to 230-volt input operation, the split primary of transformer T1 must be changed from parallel to series connection, and the fuses must be replaced, as follows:

1. Unsolder the black/red wire from TB1 (refer to Figure 8).
2. Unsolder the black/yellow wire from TB1.
3. Solder the black/red and black/yellow wires to TB2.
4. Replace the $\frac{1}{2}$-ampere fuses F1 and F2 with $\frac{1}{4}$-ampere fuses.

1. TB2 2. TB1

FIGURE 8. LOCATION OF TERMINAL STRIPS TB1 AND TB2

D. TYPICAL TEST EQUIPMENT SETUPS

Any one of several possible equipment setups can be used to measure the noise characteristic of an amplifier. The setup used is determined by the output frequency and gain of the amplifier under test.

1. OUTPUT AT IF

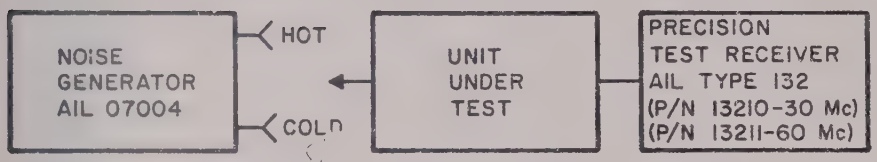


FIGURE 5. NOISE CHARACTERISTICS MEASUREMENT TEST EQUIPMENT SETUP FOR OUTPUT AT IF

If the output frequency of the unit under test is at 30 or 60 Mc, connect the test equipment as shown in Figure 5 and perform the procedure given in Section IV-C.

If the output of the unit under test is obtained directly from a mixer, a preamplifier must be used in the test equipment setup to match the mixer output impedance to the AIL Type 132 Test Receiver.

FIGURE 6. ALTERNATE NOISE CHARACTERISTICS MEASUREMENT TEST EQUIPMENT SETUP FOR OUTPUT AT IF

An alternate test equipment setup for noise measurement at IF is shown in Figure 6. The procedure to follow is given in Section IV-C. Refer to the instruction handbook for the AIL Type 74A Automatic Noise Figure Indicator for detailed operating procedures pertinent to that unit.

2. OUTPUT AT RF

Highly accurate RF attenuators are not generally available; therefore, to obtain maximum measurement accuracy, it is necessary to convert the output noise signal to an intermediate frequency. This can be accomplished in the standard manner using a mixer, local oscillator, and IF preamplifier as shown in Figure 7.

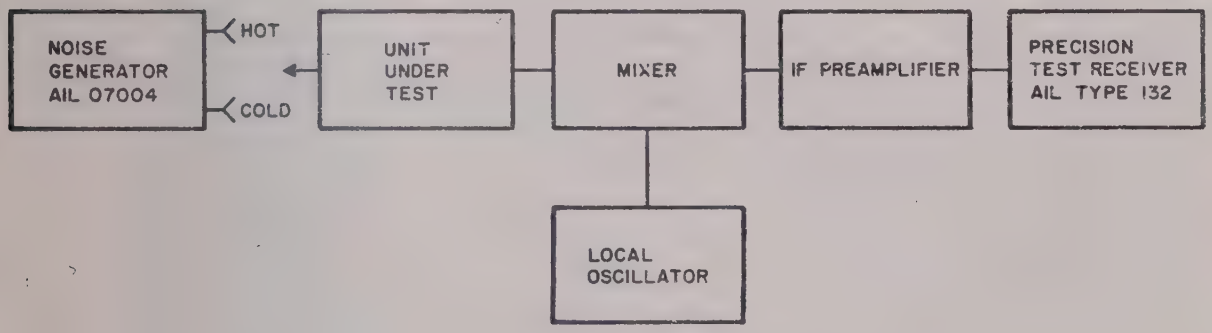


FIGURE 7. NOISE CHARACTERISTICS MEASUREMENT TEST EQUIPMENT SETUP FOR OUTPUT AT RF

An AIL Type 135 Hybrid Mixer-Preamplifier could be used in this setup. This unit is an RF mixer physically attached to an IF preamplifier. In this way, impedance matching of the preamplifier to the mixer is taken care of, and results in a low-noise conversion system that adds a minimum amount of degradation to the unit under test. The measurement procedure is given in Section IV-C.

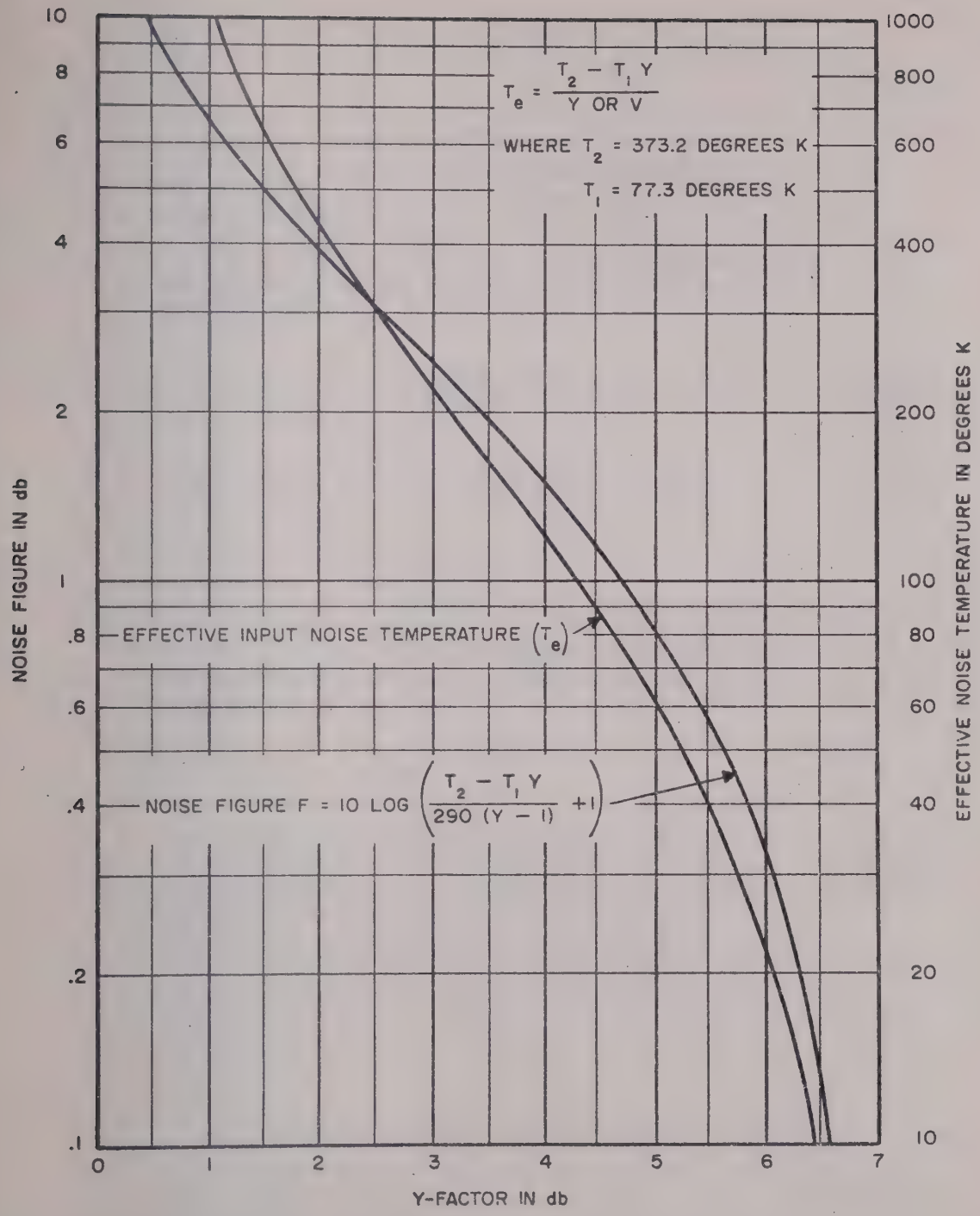


FIGURE 4. NOISE FIGURE AND EFFECTIVE INPUT NOISE TEMPERATURE VS Y-FACTOR FOR TERMINATION TEMPERATURES OF 77.3°K AND 373.2°K

4. Increase the attenuation of the variable attenuator until the meter again indicates the reference level set in step 2.

5. Note the new setting of the variable attenuator.

6. Subtract the attenuator setting noted in step 2 from that obtained in step 5. (This procedure assumes that the variable attenuator is calibrated in db.) The result is called the Y-factor.

7. Convert the Y-factor (in db) to a power ratio and compute the noise figure of the equipment under test using equation 4-1, or refer to step 9.

$$F = \frac{1.287 - 0.266Y}{Y - 1} + 1 \qquad (4\text{-}1)$$

F may then be converted to db using the standard power ratio relation:

$$F_{db} = 10 \log F$$

8. If the noise characteristics of the unit under test are desired in terms of effective input noise temperature (T_e), this quantity can be computed using equation 4-2, or refer to step 9.

$$T_e = \frac{295.9}{Y - 1} - 77.3 \qquad (4\text{-}2)$$

9. As an alternative to performing the calculations required by steps 7 and 8, noise figure (F) in db, and effective input noise temperature (T_e) in degrees Kelvin, may be read directly from Figure 4. This graph is a combined plot of equations 4-1 and 4-2 with F and T_e plotted vertically against Y-factor in db. The AIL Noise Figure Slide Rule also provides a convenient means of determining these quantities without computation.

WARRANTY

Except for tubes, fuses, and batteries which carry no warranty, Cutler-Hammer, in connection with equipment sold, agrees to correct any defect in workmanship or material which may develop during the period of one year from the date of shipment under proper or normal use and not in excess of the original manufacturer's life expectancy ratings, by its option to repair or replace, FOB point of shipment, the defective part or parts, and such correction shall constitute a fulfilment of all Cutler-Hammer liabilities in respect to said apparatus.

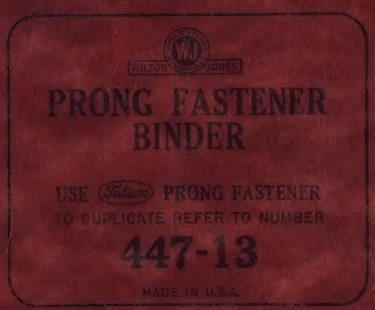
II. SPECIFICATIONS

The electrical and physical specifications of the Hot-Cold Body Standard Noise Generator (Part No. 07004) are given in Table I.

TABLE I. SPECIFICATIONS

Frequency range	0 to 6 Gc
Output impedance	50 ohms (nominal)
SWR	1.15 maximum
Differential SWR	The distance between the complex impedance points of the hot and cold terminations (plotted on a Smith chart) is less than the diameter of a circle corresponding to an SWR of 1.05.
Noise temperature*	Hot $373.2^{+2^{\circ}}_{-3^{\circ}}$ K
	Cold $77.3^{+3^{\circ}}_{-0^{\circ}}$ K
Output connectors	General Radio PRL8A with GR adapter to Type "N"
Power requirements	115 volts, 50 to 60 cps, 20 watts (for 230-volt operation, see Section IV)
Oven temperature monitor	Copper-constantan thermocouple and output jack
Nitrogen life	3 hours minimum
Dimensions	14-5/8 x 9-7/16 x 14-1/8 inches
Weight	15 pounds
Shipping weight	20 pounds

* The tolerance on the temperature of the hot termination is based on the absolute accuracy of the thermostat used, the short and long term stability, the temperature gradient across the physical termination, and the electrical loss to the front panel connector. The tolerance on the temperature of the cold termination is based on the boiling temperature of pure liquid nitrogen, the temperature gradient across the physical termination, and the electrical loss to the front panel connector.



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